Dr David Sawatzky

Any personal enquiries can be sent to sportdiving@motpub.com.au

DECOMPRESSION SICKNESS – WHAT IS IT?

Decompression sickness (DCS) is an ever-present risk in diving. We can plan our dives and lives so that the risk of DCS is minimized, but as long as we breathe compressed air under increased pressure there will be some risk of DCS. If you do enough dives over a long enough period of time you can expect to get bent. However if you have a good understanding of DCS and decompression theory, there are many things you can do to reduce the risk of developing DCS to a very low level.

To put this in perspective, there is risk in virtually everything we do, and my goal has always been to reduce the risk of being injured or killed on a dive, to less than the risk of being injured or killed on the drive to and from the dive. I have successfully used this approach on about 2,000 dives, including a lot of advanced technical dives, but I eventually did develop DCS after a dive to 90 meters (300 feet) for 60 minutes on which my drysuit leaked and I was extremely cold during the almost 2.5 hours of decompression.

In this article I am going to start with the basics and in subsequent articles progressively build up to the current level of understanding of DCS, or at least my current level of understanding! Some aspects of DCS are now quite clearly understood, some are starting to make sense, and some quite frankly don't make much sense at all.

But what exactly is DCS? DCS can be defined as, "a collection of signs and symptoms that sometimes follows too rapid decompression". We need to define a few terms. A "symptom" is what you tell your doctor is wrong with you (i.e. headache, fatigue, pain) while a "sign" is what your doctor can see or measure (i.e. a rash, blood pressure, reflexes, temperature). A "syndrome" is simply a collection of signs and symptoms that occur together while in a "disease" the cause, effect on the body, and the outcome are usually known. DCS was initially and in many ways still is a syndrome. People noticed that when a person was exposed to reduced pressure they sometimes developed a collection of signs and symptoms. It did not matter how the pressure was reduced. You could ascend a mountain, fly in an airplane, go into space, reduce the pressure in a hypobaric chamber, or you could expose your body to increased pressure by working in a caisson, going diving, or being in a hyperbaric chamber and reduce the pressure when you returned to the surface.

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People then give this collection of signs and symptoms a name, like "caisson disease" for the joint pain and other symptoms some people developed after working in a caisson, "diver"s palsy" when it happened to divers, "high altitude diver"s disease" when it happened to aviators, compressed air illness, bends, chokes, staggers, prickles, fits, aeroembolism, dysbarism, etc. It was eventually discovered that all of these syndromes were similar and that they were all related to a reduction in pressure, so they were grouped together and the name "decompression sickness" was given to all of them. No one had any idea what was causing the signs and symptoms.

Up until 1932, all signs and symptoms occurring after decompression where considered to be DCS. It was then realized, at the United States Navy submarine escape training facility in Groton, Connecticut that divers who rapidly lost consciousness after ascending from 9 msw (30 fsw) with less than one minute at depth, were not suffering from DCS but from Arterial Gas Embolism (AGE). AGE was separated from the syndrome of DCS. The pathophysiology of AGE is now well understood (so it is really a disease) and it has been described in another article (pulmonary barotrauma). However, as we delve into the details of DCS we will see that some forms of DCS also include an element of AGE so the distinction between these two problems is not always clear.

In 1650, von Guericke developed the first effective air pump and shortly thereafter (1670) Robert Boyle first observed DCS in animals. He exposed a viper to increased pressure and then immediately exposed it to reduced atmospheric pressure in a partial vacuum chamber. "The snake was tortured furiously by the formation of bubbles in the blood, juices, and soft parts of the body". He saw a bubble moving to and fro in the eye of the snake. In 1843 Triger reported the first cases of DCS in humans. He documented severe pains in two caisson workers after they emerged from the caisson. In 1854 Pol and Watelle published the first report speculating on the nature of DCS and its relationship to pressure, duration of exposure, and rapidity of decompression.

Paul Bert (1878) is considered to be the father of hyperbaric medicine. He demonstrated that DCS is primarily the result of inert gas bubbles which had been dissolved in the body according to Dalton"s and Henry"s laws, and then released into the gas phase to form bubbles in tissues and blood during or following decompression. For almost 100 years it was believed that bubbles forming in the body caused DCS and that anyone who was decompressed to the extent that they formed bubbles would have the signs and symptoms of DCS.

In the 1960"s equipment was developed that allowed the detection of moving intravascular bubbles in divers (Doppler ultrasound). It was soon learned that many divers had intravascular bubbles but did not develop any signs or symptoms of DCS. As a result, the long accepted pathophysiology of DCS was found to be incorrect.

To understand DCS you must have a thorough understanding of some basic physics, but don"t worry, I"ll make it as simple and comprehensible as possible! Air is roughly composed of 21% oxygen and 79% nitrogen (actually 78% nitrogen, 1% argon and traces of CO_2 and other gases). In these articles I will pretend air is composed of 20% oxygen and 80% nitrogen, because I want to explain the concepts, not the exact numbers. Oxygen is very important and will be the topic of future articles, but for now we will concentrate on nitrogen.

Nitrogen is an "inert gas". That means it does not take part in chemical reactions in the body. Other inert gases of relevance to diving are argon and helium (neon, krypton, and xenon are also inert gases but not usually relevant to diving).

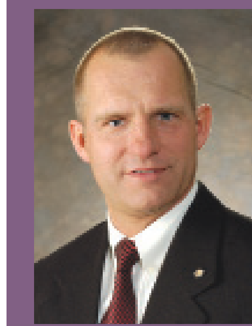
DCS can result from other gases but it is primarily the inert gases (nitrogen for recreational divers and nitrogen/helium for technical divers) that are of concern. We will explore the concept further in the future, but basically the risk of DCS is directly related to the amount of excess inert gas dissolved in the tissues of the body after a dive.

Dalton"s Law of Partial Pressure states (in simple English) that the partial pressure exerted by a specific gas in a mixture of gases is equal to the percentage of the gas in the mixture multiplied by the total pressure of the mixture of gases. For example, air at sea level has a total pressure of 1.0 atmosphere (ata). Nitrogen comprises 80% of the gas in air so the pressure exerted by the nitrogen equals 80% of 1.0 ata or 0.80 ata (the partial pressure of oxygen is 0.20 ata for a combined total pressure of 1.0 ata).

When we dive, every 10 meters (33 feet) of water has the same weight and exerts the same pressure as all of the air above the water at sea level. Therefore, at a depth of 10 meters the total pressure will be 2.0 ata (1.0 ata from the air and 1.0 ata from the water). When we are diving we are always breathing gas at the total surrounding pressure so at 10 meters depth we will be breathing air at a pressure of 2.0 ata. At this depth, the

Water Depth (metres)	Water Depth (feet)	Total Pressure (ata)	Nitrogen Pressure (ata)	Oxygen Pressure (ata)
0	0	1	0.8	0.2
10	33	2	1.6	0.4
20	66	3	2.4	0.6
30	99	4	3.2	0.8
40	132	5	4.0	1.0
50	165	6	4.8	1.2

DAVID SAWATZKY, S.C., C.D., B.Med.Sc., M.D., M.Sc., is a diving medical specialist on contract at Defence Research and Development Toronto from 1998 to 2005. Previously he was the Canadian Forces Staff Officer in Hyperbaric Medicine at DCIEM (1986-1993) and later the Senior Medical Officer at Garrison Support Unit Toronto (1993-1998). He's written a monthly column on diving medicine in Canada's *Diver* Magazine since 1993, has been on the Board of Advisors for the International Association of Nitrox and Technical Divers (IANTD) since 2000, and is an active cave, trimix and closed circuit rebreather diver/instructor/instructor trainer. David's first love is cave diving exploration and he's been exploring and surveying underwater passages in Canada since 1985. David was responsible for the exploration and mapping of almost 11 kilometres of underwater passages in the Ottawa River Cave System. In 1995, he executed the first successful rescue of a missing trained cave diver. David received the Canadian Star of Courage for this rescue which took place in the chilly Canadian waters of Tobermory, Ontario. He still dives as much as possible, but admits his five year old son Lukas, four year old daughter Emeline and wife (Dr Debbie Pestell) are currently higher priorities than diving!



pressure exerted by the nitrogen will be 80% of 2.0 ata or 1.60 ata (the pressure exerted by oxygen will be 0.40 ata for a total pressure of 2.0 ata). At 20 meters depth the total pressure will be 3.0 ata and the partial pressure of nitrogen will be 2.4 ata as shown in the table.

Henry"s Law of Solubility tells us that "at a constant temperature the amount of a gas that will dissolve in a liquid is directly proportional to the partial pressure of that gas over the liquid". Therefore, if we are living at sea level and have not been diving or flying recently, the partial pressure of nitrogen in all of the tissues of our bodies will be the same as the air we are breathing (0.8 ata). The partial pressure of oxygen in the tissues will be much less than 0.2 ata because the tissues are continuously using up the oxygen.

If we put on our dive gear and dive down to 10 meters depth, the air we are breathing will have a partial pressure of nitrogen (pN2) of 1.6 ata, but the tissues in our bodies will only have a pN2 of 0.8 ata. Therefore, nitrogen will be "pushed into our bodies" with a pressure of 0.8 ata (1.6 ata minus 0.8 ata). Over time the pN2 in our bodies will rise. As it increases the difference between the pN2 we are breathing and the pN2 in our bodies will become smaller and as a result the pressure pushing N2 into our bodies will become less. Therefore, when we first dive down to a depth, N2 will move into our bodies rapidly but the longer we stay there the slower the rate of N2 uptake. When the pN2 in our bodies is the same as the pN2 in the gas we are "pushed into our bodies" with a pressure of 0.8 ata (1.6 ata minus 0.8 ata). Over time the pN2 in our bodies will rise. As it increases the difference between the pN2 we are breathing and the pN2 in our bodies will become smaller and as a result the pressure pushing N2 into our bodies will become less. Therefore, when we first dive down to a depth, N2 will move into our bodies rapidly but the longer we stay there the slower the rate of N2 uptake. When the pN2 in our bodies is the same as the pN2 in the gas we are breathing, no more N2 will be taken up by our bodies and we are said to be "saturated" with N2.

The reverse process happens when we ascend. Gas will leave the body quickly at first but as the pN2 in the body is reduced, N2 will leave the body at a slower rate. This brings us to the first fundamental concept required to understand DCS, "the uptake (and elimination) of inert gas by the body follows an exponential curve". This principle was figured out by John Scott Haldane in the early 1900s.

In the next article we will continue this discussion of the basic physics and physiology that are related to decompression sickness.

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